Development of the self fluxing alloy fusing process with the control system using the simulation

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Abstract :
Self fluxing alloy has the characteristic that objective hardness is provided by performing re-fusion (fusing) after spray. This again molten work is carried out by hands, and stability of the quality and improvement of the work efficiency usually become the problem. Therefore we aim at the quality stability of the self fluxing alloy fusing process and the improvement of the work efficiency by using high frequency induction heating. I utilize induction heating simulation of JMAG as a part of the study.
I performed an induction heating experiment for the boiler tubes which a lot of self fluxing alloy was used for this time. I report the result that weighed the differences between experimental value and analysis level at that time.

Development of the Self Fluxing Alloy Fusing Process With the Control System Using the Simulation

−Comparison of experiment value and analysis result−

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Report contents

1-1. Company brochure

Company name	NIPPON THERMONICS. Co.,Ltd
Location of corporate headquarter	1-13-6, Tanashioda Sagamihara city Chuo-ku Kanagawa pref. 252-0245, Japan TEL：+81 42-777-3411 FAX：+81 42-777-3277
Established	9/1/1973
Business lineup	Manufacturing and distribution of high-frequency application equipment and ultrasonic wave application equipment Manufacturing and distribution of automated control equipment and power saving equipment
Capital stock	40 million yen
Employees	45 (Electrician and mechanical engineering technician: total 34)
Major products	-High-frequency induction heating application equipment High-frequency induction heating, tempering, shrinkage High-frequency metallic melting (air, vacuum, and various atmospheres) High-frequency forging heating High frequency power supply for semiconductor manufacturing equipments - Design and manufacture of special control units and automatic equipments
URL	http://www.thermonics.co.jp

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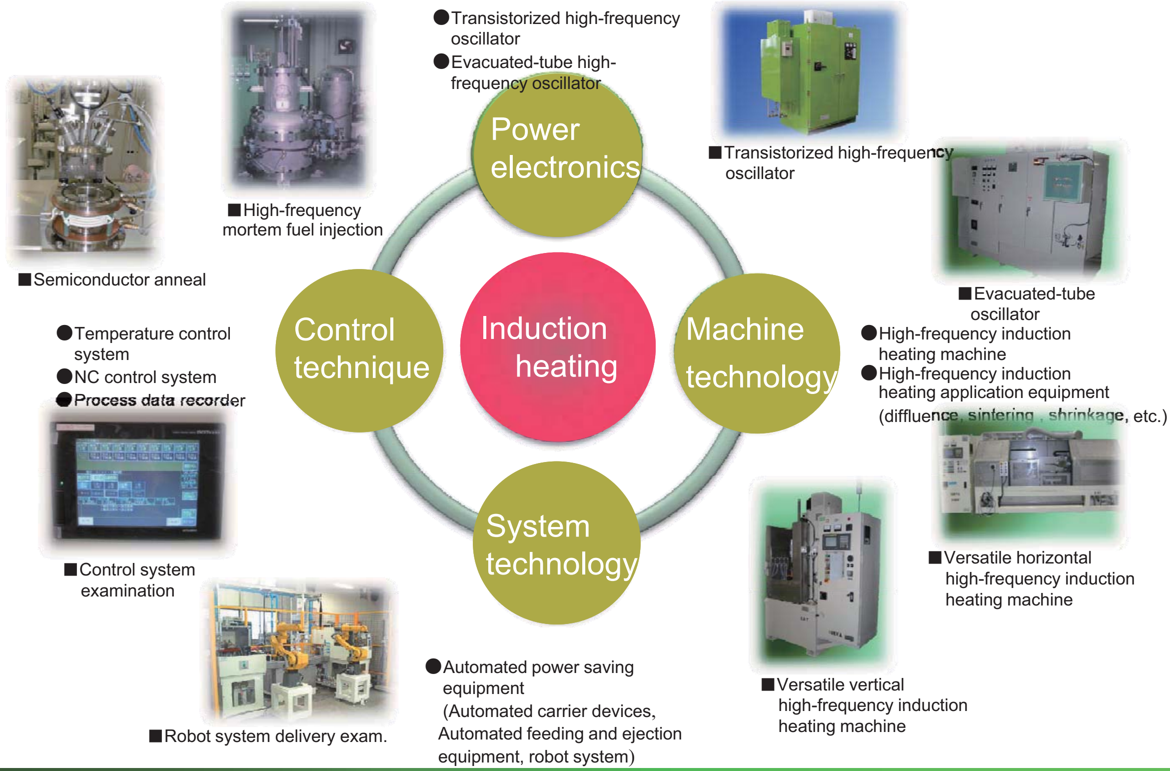
1-2. Product introduction



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2-1.Research outline

Thermal spraying of autogenic alloy is performed on boiler tubes used at thermal power plants or incinerators in order to improve their abrasion resistance. It is possible to change their hardness considerably by remelting (fusing) the autogenic alloy film after performing thermal spraying.

Traditional technology

In traditional remelting (fusing) works, a skilled technician handles a torch and works while visually checking the remelting status of the film. Such kinds of manual procedures do not increase productivity, and they have problems with passing on techniques from skilled technicians.

New technology

Changing the method from torch heating to high-frequency induction heating leads to the improvement of productivity and reproducibility. However, heating a whole material with high-frequency induction heating requires years of experience. Magnetic field and thermal analysis simulation will solve this kind of problem.

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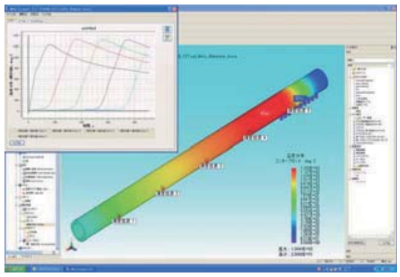
2-2. Research flow of the magnetic field and thermal analysis



Introduction

- -Introducing JMAG
- -Attending lectures
- -Checking the parameter influences

Investigation

- − Comparison of experiment and analysis values

Operation

- -Establishing a method for estimating coil current value
- -Applying to the control system
- -Collecting the operation data

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3-1. Experiment objective

Compare the temperature that JMAG calculated to the experiment value, and check the difference.

<Target values>

Melting temperature (eutectic point): 1052℃
Fusing temperature: 990 degrees C to 1160 degrees C
Temperature measurement error: 2%

The difference between experiment and analysis values must be 4% or less.

$$\text{Difference between experiment and analysis values } \varepsilon(\%) = \frac{(\text{Analysis value} - \text{Measured value})}{\text{Measured value}} \times 100$$

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3-2. Experiment device

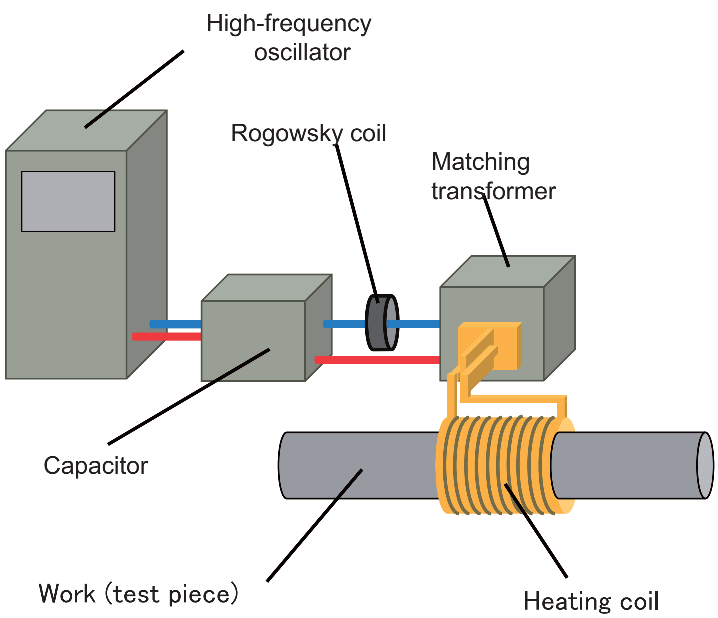

Fig.1 Outline drawing of the experiment device

Fig.2 Experiment device photo

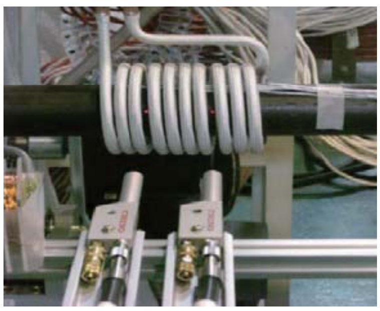

Fig.3 Magnified heating coil

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3-3. Work (test piece) geometry and measuring point

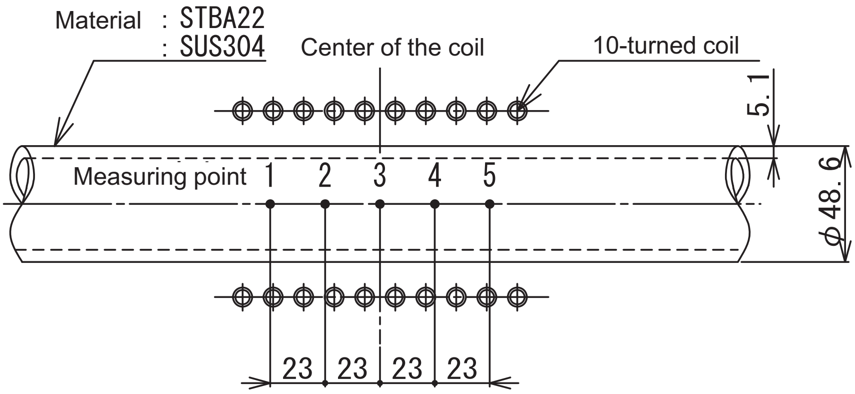

Fig. 4 Work dimension and measuring point

Table 1 Material properties table

Name	Category	Standards	Properties
STBA22	Alloy steel pipe for boiler and heat exchanger	JIS G 3462	Magnetic material
SUS304	Stainless steel pipe for pipework	JIS G 3459	Non-magnetic material

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3-3. Analysis Conditions

1. Analysis model JMAG-Designer(x64) 10.4.04h

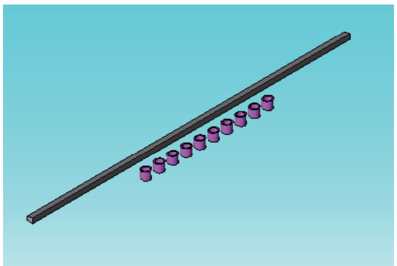

Fig. 5 Picture of analysis model

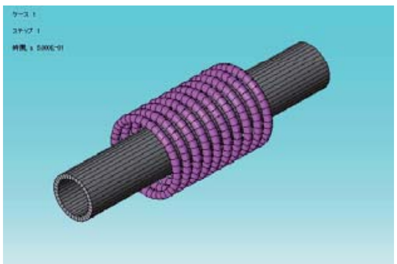

Fig. 6 Picture of full model

Table 2 Condition table for magnetic field analysis

Magnetic field analysis	
Model size	299.9 x 52.47 x 2100
Analysis type	Frequency response analysis
Full model conversion	36
Solution when not converged	A-φmethod 1
Air region	7 times of model

Table 3 Condition table for thermal analysis

Thermal analysis	
Model size	23.87 × 7.49 × 300
Analysis type	Transient thermal analysis
Initial temperature	20℃
Radiant heat transfer	0.6
Analysis step	0.5s/step

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3-3. Analysis Conditions

2. Each parameter

Frequency control : Regular intervals 7.5kHz (STBA22)

: Regular intervals 6.4kHz (SUS304)

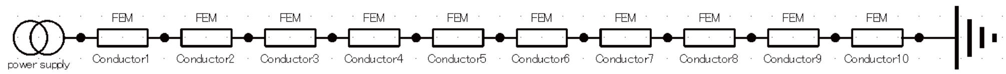

Fig.7 Analysis circuit diagram

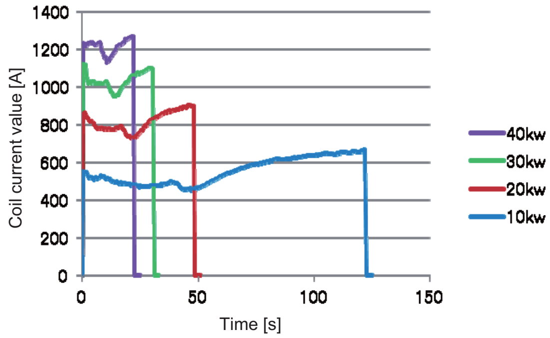

Fig. 8 Input coil current value

Table 4 Material properties source

Material properties	STBA22	SUS304
Magnetic properties	Experiment value	Estimate value
Electric conductivity	Estimate value	Ref. document value
Thermal conductivity	Experiment value	Ref. document value
Specific heat	Estimate value	Ref. document value

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4-1. Experiment results of iron pipe (STBA22)

1. Using the T-μ curve

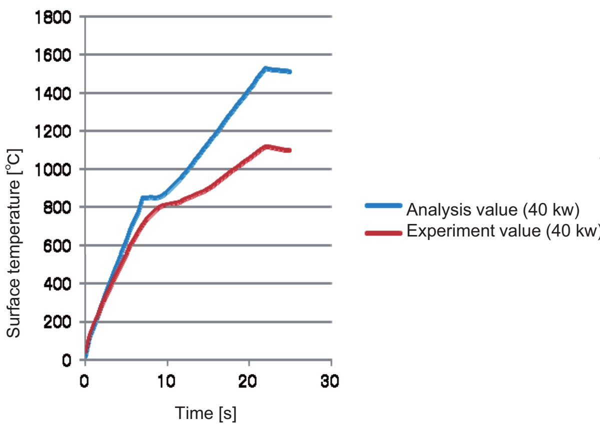

Fig.9 Temperature shift when heating STBA22 (40kw)

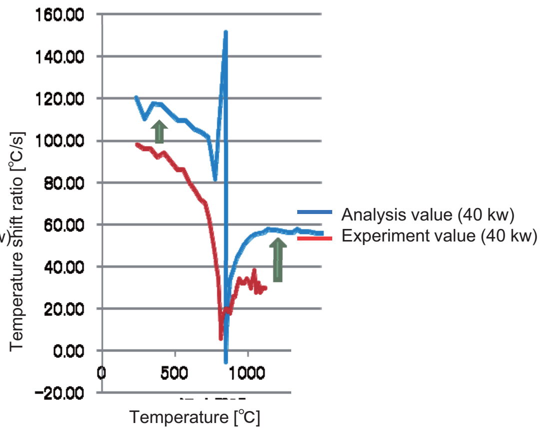

Fig.10 Temperature shift ratio when heating STBA22 (40kw)

The temperature shift ratio of the analysis value was larger than the experiment value on the total heating temperature range.

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4-1. Experiment results of iron pipe (STBA22)

2. Using the BH curve

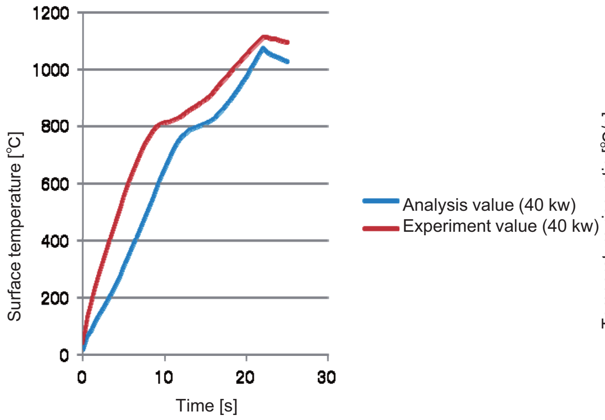

Fig.11 Temperature shift when heating STBA22 (40kw)

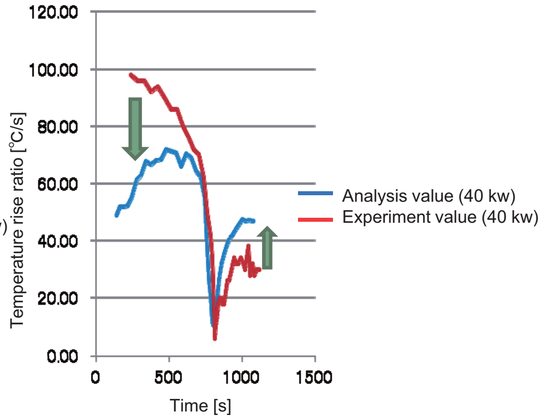

Fig.12 Temperature shift ratio when heating STBA22 (40kw)

The temperature shift ratio of the analysis value was smaller than the experimental value up to around 500 degrees C, and larger than the experiment value over 800 degrees C.

4-1. Experiment results of an iron pipe (STBA22)

3. Study of oscillatory circuit characteristics

- The oscillator is a fixed voltage-type parallel inverter method
- It has a built-in automatic frequency adjustment device, and can react to load changes.

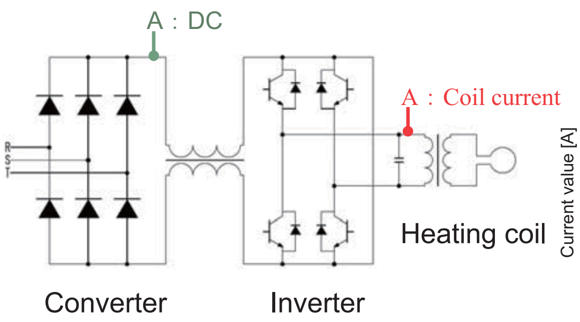

Fig.13 Oscillatory circuit diagram

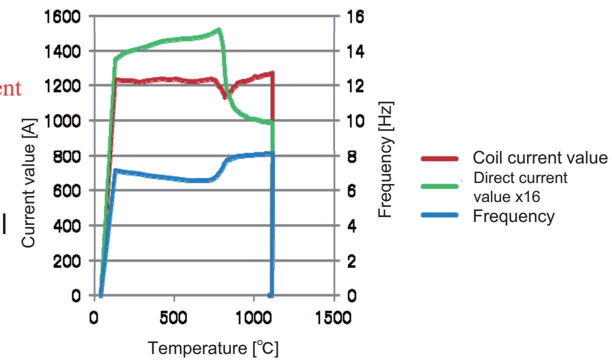

Fig.14 Current and frequency shift (40kw)

Load changes result in the change of oscillatory frequency.

Change the thermo physical property parameters, and react to frequency changes.

4-1. Experiment results of iron pipe (STBA22)

4. Changing the electric conductivity parameters

We consolidated all the differences between simulation calculation and measurement value to the curve (temperature dependency), and checked the electric conductivity curve that gives the same result as measurement value.

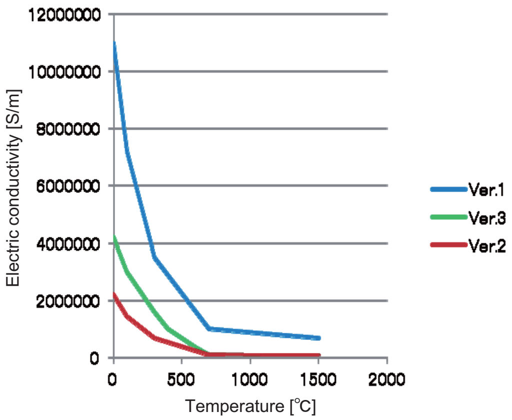

Fig.15 Electric conductivity parameter

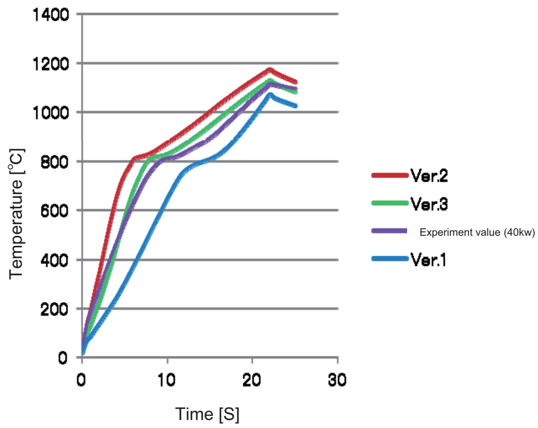

Fig.16 Relationship between electric conductivity and temperature shift (40 kw)

Electric conductivity ver.3 indicated the closest value compared with the experiment value.

4-1. Experiment results of iron pipe (STBA22)

4. Changing the electric conductivity parameters

・We confirmed the difference between the measurement and analysis values.

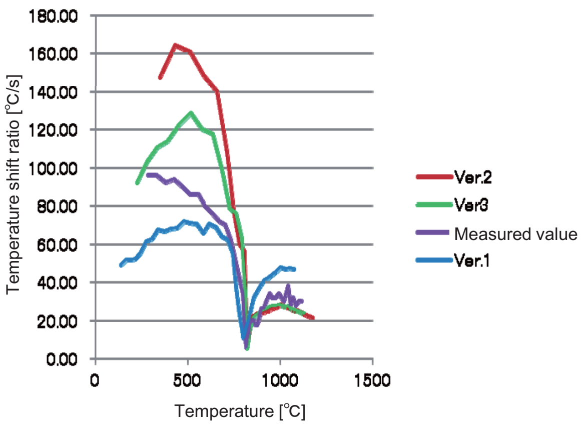

Fig.17 Relationship between electric conductivity and temperature shift (40 kw)

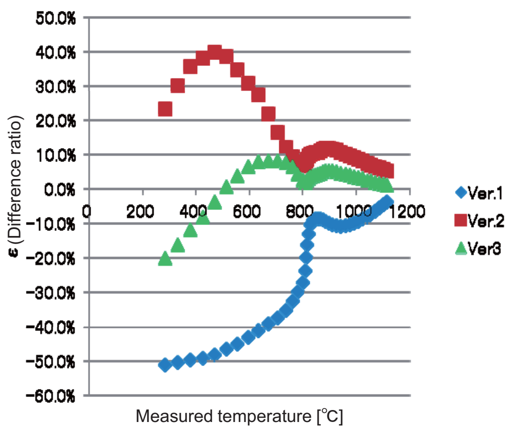

Fig.18 Difference ratio between experiment and analysis values (40 kw)

With electric conductivity ver.3, the difference between the measurement and analysis values was 2.4% when the target temperature is 1050 degrees C, and it stayed within the 4% of our target value.

4-1. Experiment results of iron pipe (STBA22)

5. Verification with the other output

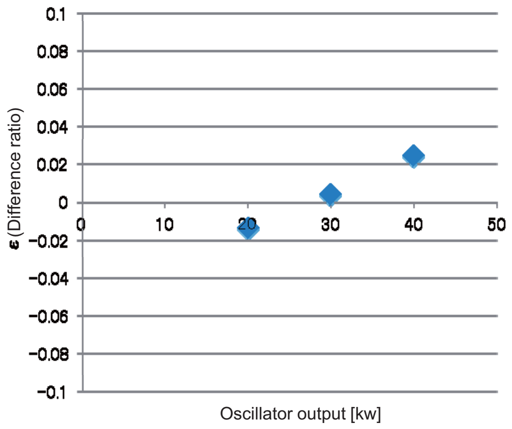

Fig. 19 Different ratio of each oscillator output (STBA22)

6. Verification with each measuring point

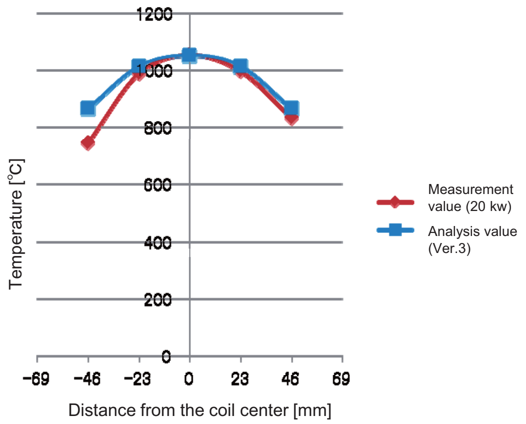

Fig. 20 Temperature distribution at each measuring point (20kw)

-With other outputs, the difference between measurement value and analysis value stayed within the 4% of our target value as well.

- At each measuring point, the measurement value and analysis value almost matched.

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4-2. Experiment result of stainless pipe (SUS304)

1. Using the T-μ curve

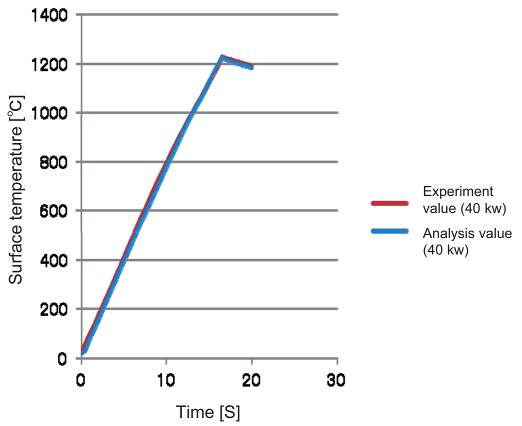

Fig.21 Temperature shift when heating SUS304 (40kw)

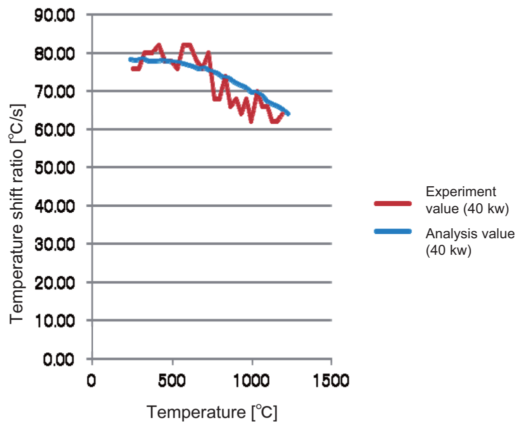

Fig.22 Temperature shift ratio when heating SUS304 (40kw)

Analysis using the T-μ curve output values that considerably matched with the experiment value.

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4-2. Experiment result of stainless pipe (SUS304)

2. Oscillator circuit characteristic

3. Difference between experiment and analysis values

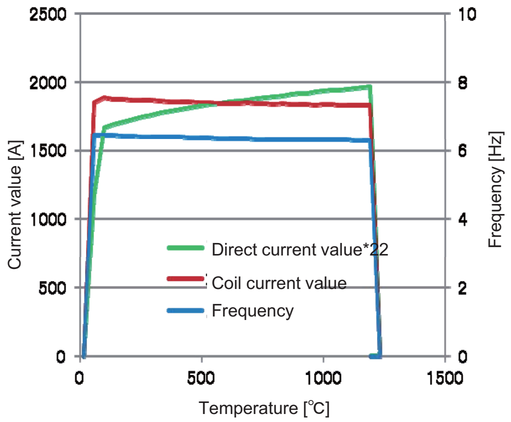

Fig.23 Current when heating and frequency shift (40kw)

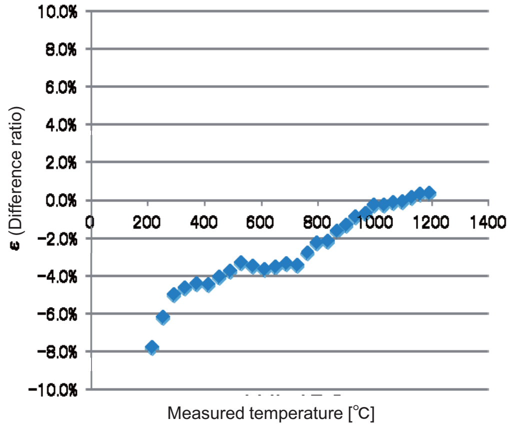

Fig.24 Difference ratio between experiment and analysis values (40kw)

The difference between the measurement and analysis values was -0.2% when the target temperature was 1050 degrees C, and stayed within the 4% of our target value.

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4-2. Experiment result of stainless pipe (SUS304)

4. Verification with the other output

5. Verification with each measuring point

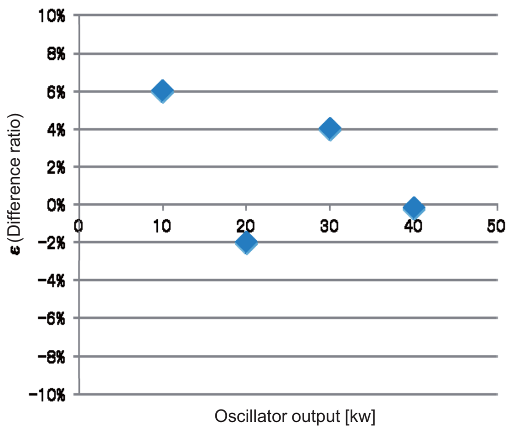

Fig. 25 Different ratio of each oscillator output (SUS304)

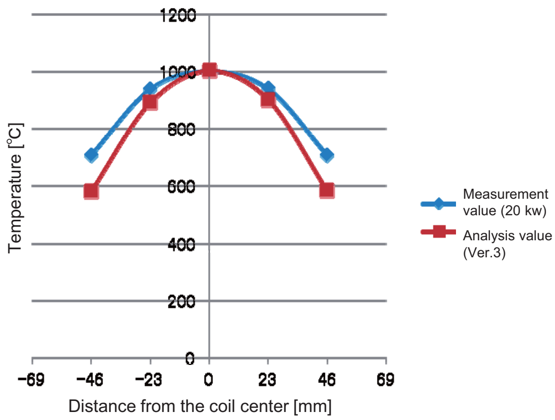

Fig. 26 Temperature distribution at each measuring point (20kw)

As oscillatory frequency changes due to load changes are small, the difference between experiment and analysis values stayed within the target error.

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5. In conclusion

Setting the appropriate electric conductivity curve resulted in obtaining simulation results that are considerably close to the experiment value.

When carrying out an induction heating simulation using a high-frequency oscillator of voltage constant type parallel inverter method:

1. In case of using STBA22 (large load changes)

   As oscillatory frequency changes due to load changes are large, it is necessary to set parameters that account for the frequency change span.

2. In case of using SUS304 (small load changes)

   As oscillatory frequency changes due to load changes are small, even calculations with fixed frequency will output low-error results.

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Thank you very much.

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